Global Scientific JOURNALS

GSJ: Volume 13, Issue 11, November 2025, Online: ISSN 2320-9186

www.globalscientificjournal.com

ENHANCING FAULTS DETECTION AND MITIGATION OF SYNCHRONOUS GENERATOR IN POWER GENERATION STATION USING ARTIFICIAL NEURAL NETWORK

By

Okoro Felix, Uju I. U., Jams A. Obineche and A. W. Nwosu

Department of Electrical and Electronic Engineering,

ChukwuEmeka Odumegwu Ojukwu University

Uli, Anambra State, Nigeria.

Author e-mail: felixokoro39@gmail.com

Abstract

This paper aim to classify, detect and mitigate the technical faults in a synchronous generators in a power generation system. The paper utilized artificial neural network, ANN to ensure prompt fault classification, detection and mitigation to avoid a sudden shut down of the plant due to fault cascade. The case study was the synchronous machine plant being utilized in Ibom power plant in

Akwaibom state, Nigeria. The operational parameters of the plant was obtained with the mathematical model carried out to obtain the speed and temperature of various fault conditions. The conditions considered in the modeling were the operation of the plant at healthy or normal condition, lack of frequency control and occurrence of wear and tear in the rotor and machine blade. For the identification and classification of faults, the input to the ANN was the speed and temperature of the plant at normal condition and faulty condition while the target data was the fault classification code. For the fault mitigation process, the input data to the ANN was the speed and temperature of the plant at faulty condition while the target data to the ANN model was the speed and temperature of the plant at healthy or normal condition. From the outcome of the simulation, the speed and temperature data were obtained.

Introduction

Synchronous machine also known as synchronous generator or motor is an electrical machine that operates at a constant speed that is synchronized with the grid frequency to which it is connected. Synchronous generators are widely used in powering industrial applications, and transportation, they also play a crucial role in maintaining the stability and reliability of electrical grids. In synchronous generator, a direct current must be supplied to the field circuit on the rotor using slip rings and brushes mounted on the rotating shaft of the synchronous machine. Synchronous motor converts electrical energy into mechanical energy, the rotor rotates at the speed of the revolving field supplied by the balance of three phase stator magnetic field in the machine (Adamsab, 2021 and Isidore U et al 2018).

Scope of the Paper

It has become imperative to analyze the operating synchronous machines in the Nigerian power system network. The system of study utilized in the research would analysis the operation parameters of the synchronous system with and without (with loads and no fault would represent the normal operation condition of the plant). The mathematical models utilized were represented in Simulink and simulations were done where the current signal, voltage signal and speed of the plant were analyzed (at normal condition and faulty conditions). The current signal being the most sensitive parameter was utilized for the identification of fault that occurs in the plant. The Artificial neural network model was designed to have the current signals of normal condition and faulted condition as the input and the identification code as the target and invariably the output. The generated ANN model was utilized as a measure for the detection and identification of the class of fault occurrence in the synchronous machine. For the mitigation process, the ANN model was utilized. In this case, the input to the model were the faulted current signals while the target variable was the current signal at normal condition. The essence of the fault mitigation with ANN was to determine the time of which the ANN can hold prior to the occurrence of any fault in the synchronous machine. Each of the model generated was implemented and simulated with SIMULINK/ Matlab.

Features of Synchronous Generator

The synchronous generator has several distinctive features which makes it suitable for various application in power generation and transmission systems, some of these features includes: Synchronization with the power system, operation speed, output power, excitation system, power factor controls, higher efficiency and large power generation capacity (Baghdasaryan et al, 2023; Benkaihoul et al, 2024 and Felix, 2023).

i. **Synchronization with the power system**: Synchronous generators have the ability to operate in synchronism with the existing power system. They are capable of matching the frequency, voltage and the phase angle of the power grid before being tied to the grid this enhances grid stability and efficient power transfer.

ii. **Operation Speed:** synchronous generator operates at a constant speed known as synchronous speed which is determined by the frequency of the power system, the rotor rotates at a fixed speed enhancing its synchronization with the grid.

iii. **Excitation system:** synchronous generators require an excitation system to supply DC current to the rotor windings. This current creates the magnetic field on the rotor, which interacts with the stator winding to produce electricity.

iv. **Power factor control:** synchronous generator keeps the power factor under control. By adjusting the field current supplied to the rotor, the generator can operate with a lagging or leading power factor depending on the grid's requirements, this is actualized by connecting synchronous reactors that generates reactive power (VARs) into the grid. This characteristic makes the synchronous generator essential in power system where power factor correction and reactive power control are important.

v. **Higher Efficiency:** The efficiency of synchronous generator is higher compared to other types of electrical machines; the efficiency is achieved because it operates at synchronous speed and have minimal losses in the rotor and stator windings.

vi. **Large power generation capacity:** synchronous generators are capable of handling high power generation capacities. They are commonly used in power plant and large-scale industrial application where substantial amounts of electrical power are needed.

Synchronous machine faults

There are two main categories of SMs' faults: mechanical and electrical faults as shown in Figure 2.18 Stator electrical faults are ~30–40%, while rotor faults are around 5–10%. Mechanical faults, like eccentricity and bearing faults, present a percentage of 40–50%. These faults percentages were stated in several failure detection surveys (Al-Greer et al, 2023). Other possible external faults can occur due to incorrect connection of stator winding or utility supply unbalance.

Rotor failures are caused by a combination of different stresses that act on the rotor due to electromagnetic, thermal, dynamic, environmental and mechanical aspects. Broken rotor bars (BRBs) causes are (AlShorman et al, 2020; Akbar et al, 2023, *Asanya O. N., et al, 2023,* and Uchechukwu et al, 2022):

i. Thermal stresses during direct on-line starting or overload that cause overheating of the rotor cage.
ii. Magnetic stresses due to electromagnetic forces, unbalanced magnetic pulls, electromagnetic noise, and vibrations.
iii. Dynamic stresses as a result of pulsating mechanical loads, voltage fluctuation, shaft torque oscillation and centrifugal forces.
iv. Mechanical stresses because of loose lamination, fatigued parts and bearing failure.
v. Residual stresses due to imperfections in the manufacturing process of the rotor cage.
vi. Environmental stress from contamination and abrasion of the rotor material due to chemicals or moisture exposure.

Methodology

The applications utilized in the paper were;

i. SIMULINK; this application was utilized for the modeling of the synchronous machine gas plant utilized in Ibom Power generation station, obtaining the speed and temperature of the plant at various specified issues and development of artificial artificial neural network for identification of the issues.
ii. MatLab; this application was utilized for mathematical computations and generation of charts and plots.

The main aim of the study was to utilized artificial neural network for the detection and mitigation of faults in a synchronous gas plant using temperature and speed of the gas plant as the main parameters. The first step to achieving this was to obtain information about the gas plant from the power generation station in Nigeria.

The table for the data acquisition from Ibom power plant was shown below:

Transmission Network	Installed Capacity	Available Generation Capacity	Output Voltage	Power	Speed	Power Factor
132KV	191MW	114MW	10.7KV	33.47MVA	3000RPM	0.38

Exciting Current	Exciting Voltage	Frequency	Field Current	Ambient Temperature
6.1A	48.9V	50Hz	2781A	45^0C

The information obtained was modeled in SIMULINK and the temperature and speed were generated at various issues. The faults monitored were; when the power plant operates at normal condition, at occurrence of wear and tear in any part of the machine such as the blade, rotor and any other issue and issues with the frequency control of the plant. The temperature and speed at these issues were obtained and used as input data to the artificial intelligent model and the issue code was used as the target data to the model.

Model of the identification of technical faults in the synchronous Machine

The issues monitored and modeled in the plants were; when the power plant operates at normal condition, at occurrence of wear and tear in any part of the machine such as the blade, rotor and any other issue and issues with the frequency control of the plant. The model for the normal operation related to the speed S_p and Temperature T_p of the power plant was shown in equation below.

$$S_p = 120 \times E_{ff} \times \frac{f}{100 \times N_p} \quad (1)$$

Where S_P represents the speed of the plant, f represent the frequency and N_p represents the number of poles in the plant.

The temperature of the plant at normal condition was shown below;

$$T_n = Q_H \times E_{ff} \times \frac{f}{100} \quad (2)$$

Where T_n represents the temperature of the plant at normal condition and Q_H represents the enthalpy of the power plant operational at normal condition.

The speed and temperature of the plant during the occurrence of wear and tear was shown in the equations below;

$$S_{wt} = \frac{120 \times E_{ff}}{1.51} \times \frac{f}{100 \times N_p} \quad (3)$$

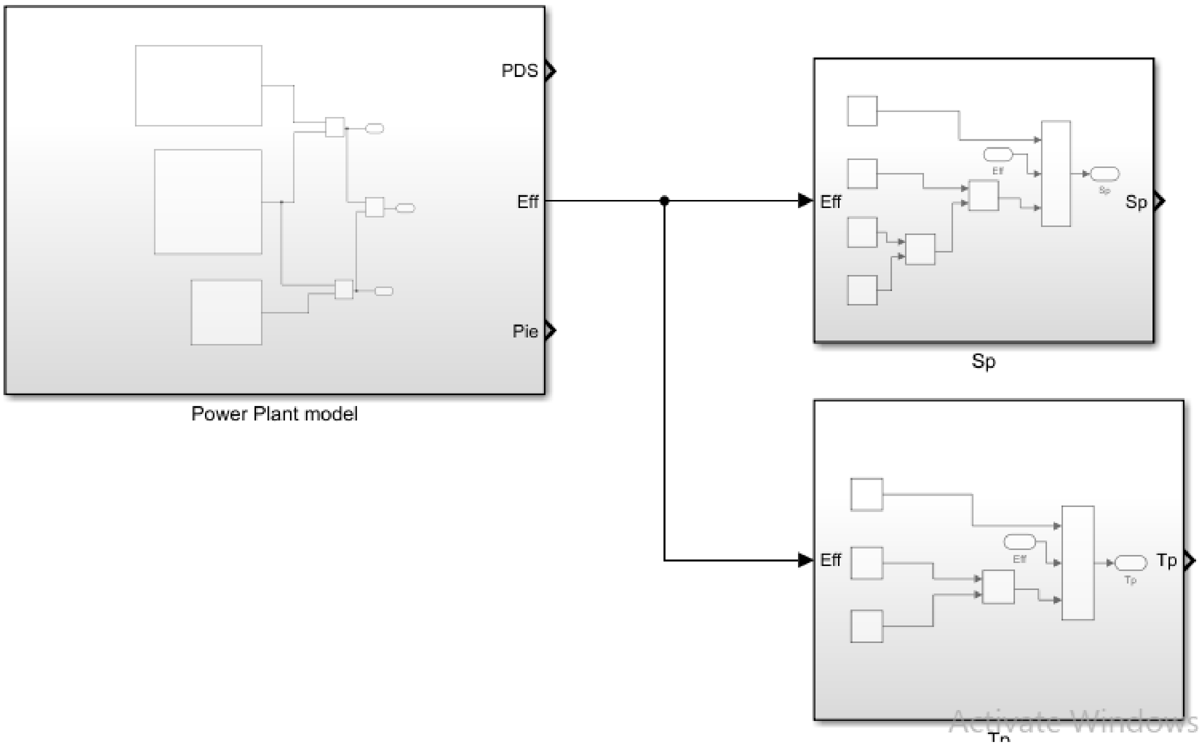
$$T_{wt} = 1.27 Q_H \times \frac{E_{ff}}{1.51} \times \frac{f}{100} \quad (4)$$

The speed and temperature of the plant during lack of frequency control of the plant was shown in the equations below;

$$S_{pn} = \frac{120 \times E_{ff}}{1.27} \times \frac{1.3f}{100 \times N_p} \quad (5)$$

$$T_n = 1.31 Q_H \times \frac{E_{ff}}{1.27} \times \frac{1.3f}{100} \quad (6)$$

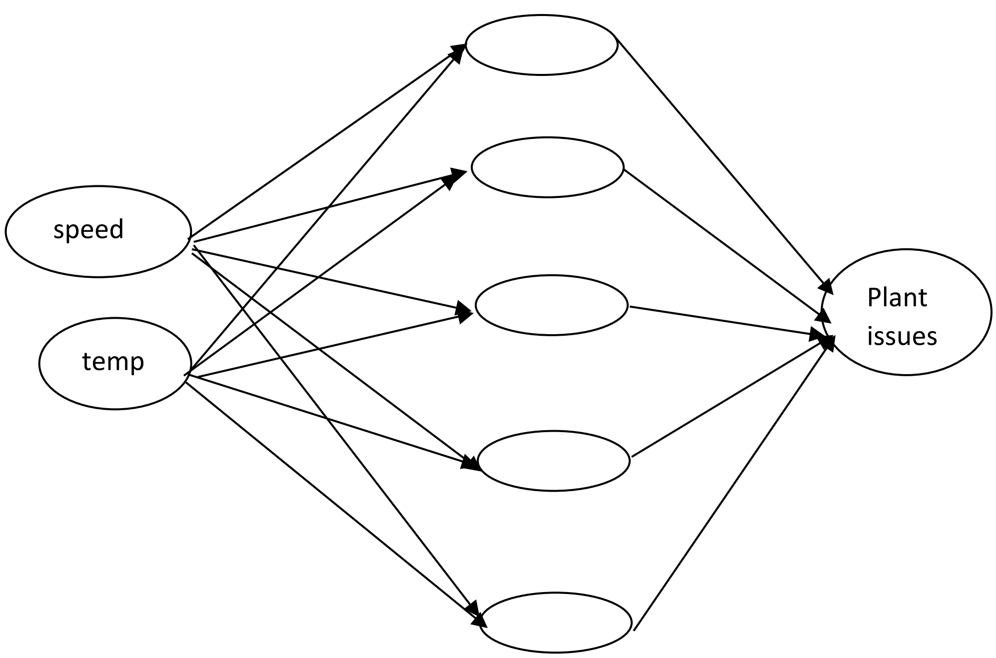
The issues outlined in this project were modeled in SIMULINK and shown in the figure below.



SIMULINK model of the plant model with plant conditions/issues

Modeling with Artificial Neural Network

The ANN architectural model utilized in the detection of the power plant issues were shown below



Structure of the ANN model

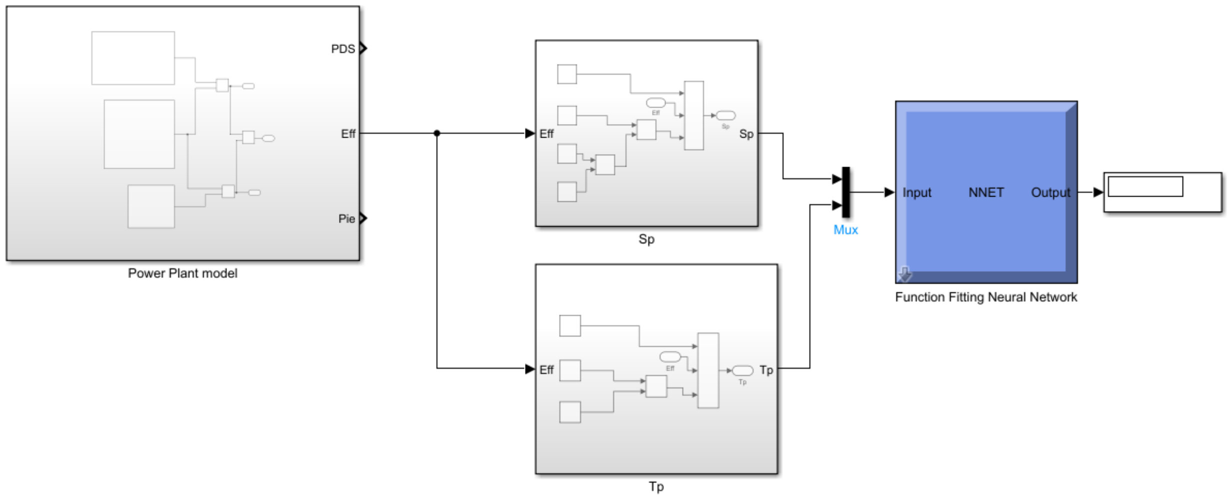
The architecture of the ANN shown implied that there two input variables which had two input neurons, five hidden neurons and one output variable with one neuron. The input variables to the ANN were speed and temperature at the corresponding plant issues. The output variable was the code for the identification and the detection of the particular plant issue. The speed and the temperature of the ANN were the major parameters from the synchronous machine utilized for the determination of the issues or faults that occurred in the synchronous machine. The issues that was identified in the generation plant was presented in the table above. While the speed and the temperature represents the operation of the generation plants that was utilized to indicate the several occurrence of faults in the plant. Since the input parameters was 2, the number of input neurons in the input layer was two with each neuron representing the input variable utilized. The hidden neurons selected for the ANN modeling was 5. The choice of 5 hidden neurons was to avoid over-fitting and under fitting issues that reduces the performance of the ANN model in detecting and mitigating faults. For high performance, levenberg marquart back propagation training algorithm was utilized for the training of the ANN model.

The codes utilized for each of the synchronous plant issues were shown in the table below

Code for the identification of the plant issues

Plant issues/ condition	Code
Normal Condition	1
Occurrence of Wear and Tear	2
Lack of Frequency Control	3

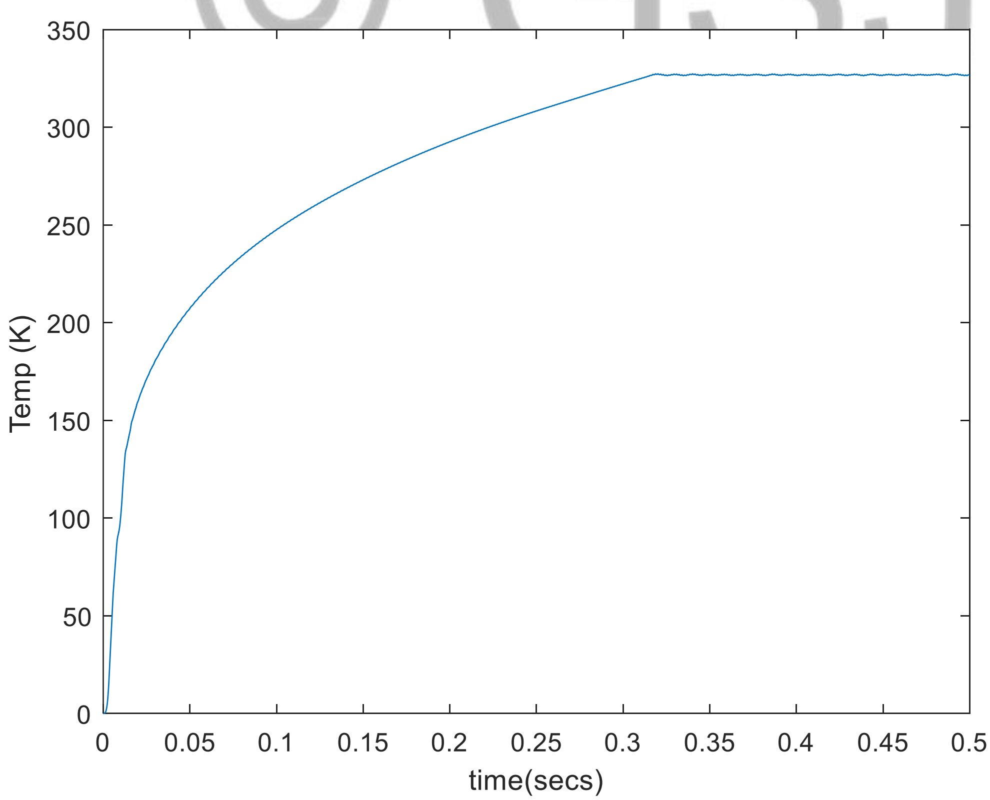
The Simulink model of the issues with the synchronous machine and the ANN for the detection and classification of the issues was shown below



Synchronous plant model with ANN sensor model

Results of the temperature and Speed of the Synchronous generator at various operating conditions

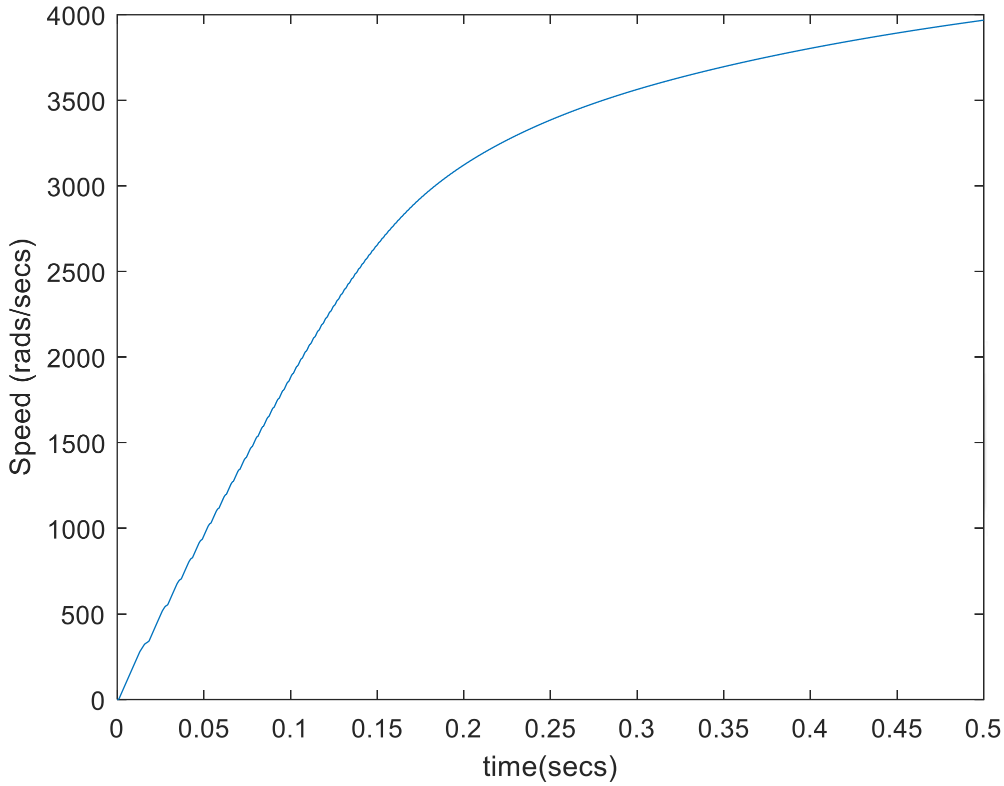
The plot for the temperature of the system at normal and healthy condition was shown below



Temperature of the synchronous generator at normal condition

The temperature of the synchronous machine simulated was shown above. From the result displayed, it was seen that the temperature increased from 0(k) and normalized at 330K, The outcome shows that the system operated at normal condition devoid of technical faults.

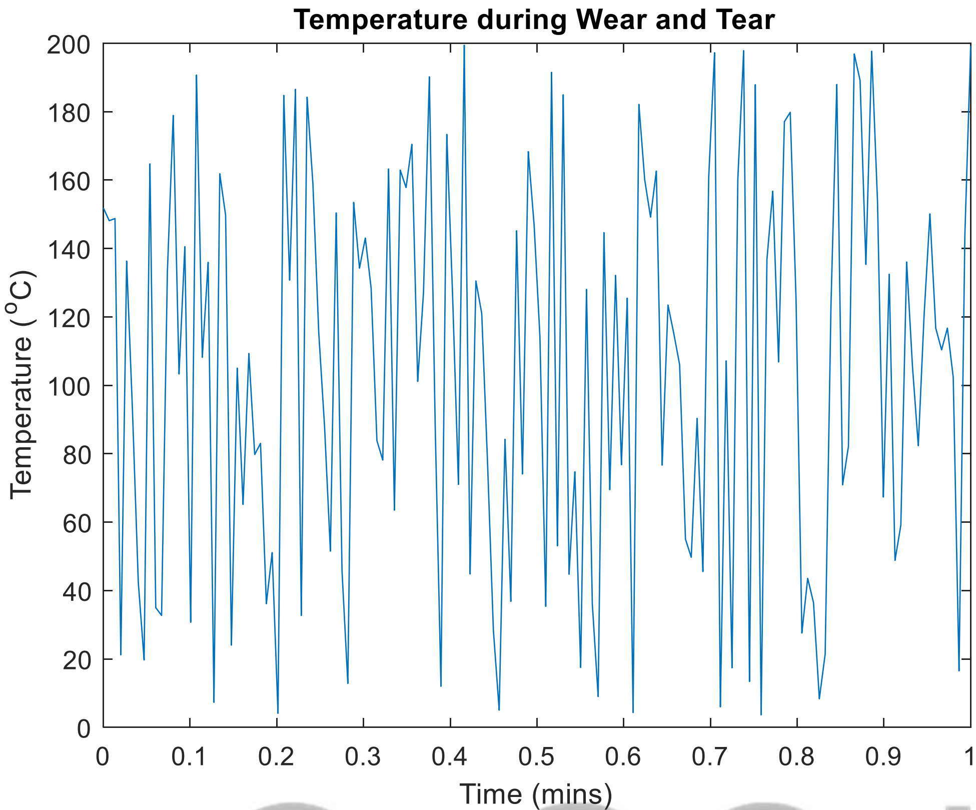
The plot for the speed of the system at normal and healthy condition was shown below



Speed of the synchronous generator at normal condition

The speed of the synchronous machine simulated was shown above. From the result displayed, it was seen that the speed increased from 0(rads/secs) and normalized at 4000rads/secs. The outcome shows that the system operated at normal condition devoid of the occurrence of technical faults.

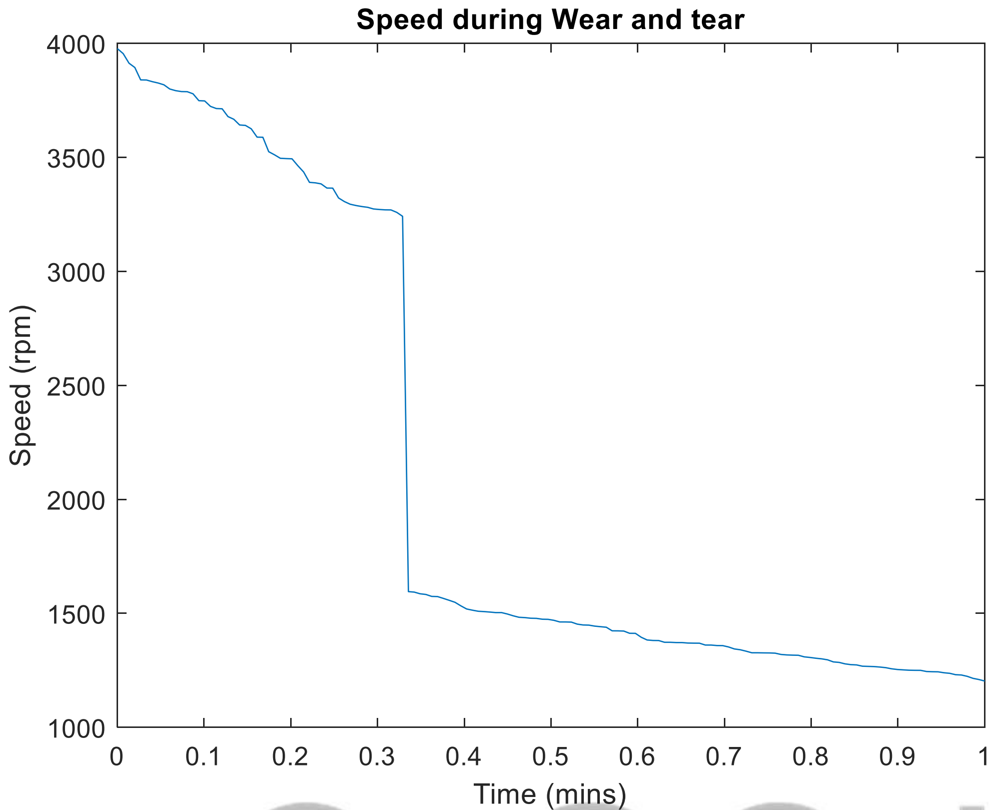
The plot for the temperature of the system at wear and tear condition was shown below



Temperature of the synchronous generator wear and tear

The impact of wear and tear in the generator plant on the temperature was shown above. It was observed that the temperature was very unstable and highly unstatic as a result of disturbances in the generator plant.

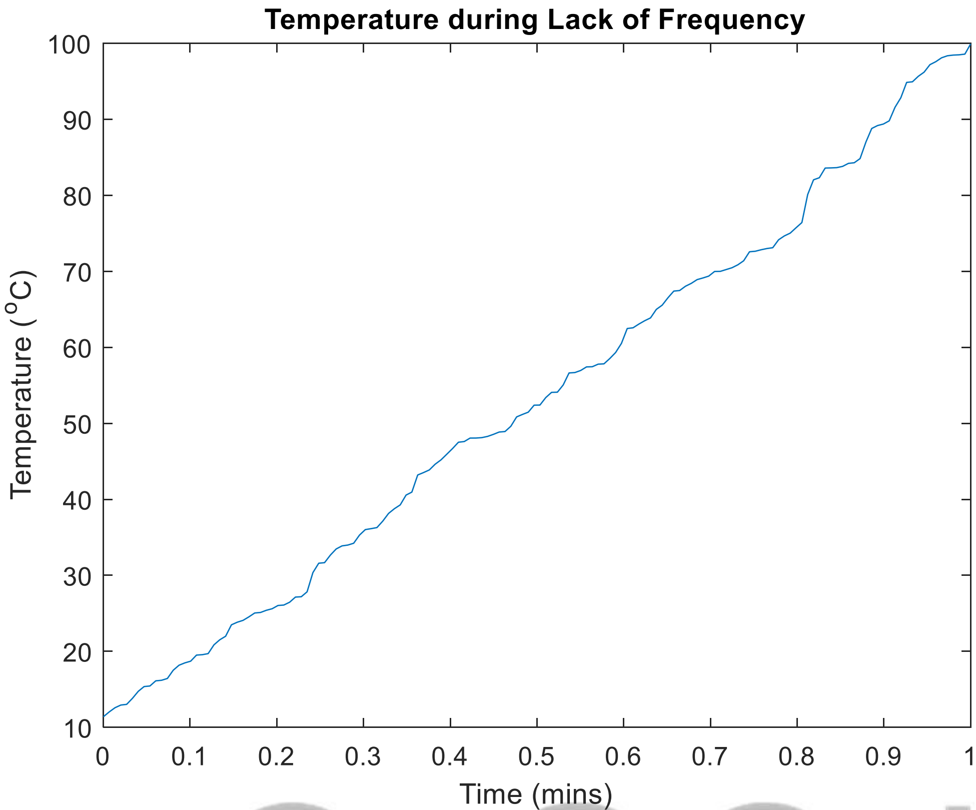
The plot for the speed of the system at wear and tear was shown below



Speed of the synchronous generator at wear and tear

The speed of the synchronous generator during the occurrence of wear and tear was shown above. The speed of the plant reduces during the occurrence of the fault. The drastic in speed of the generator simply represents the occurrence of wears in any part of the generator plant.

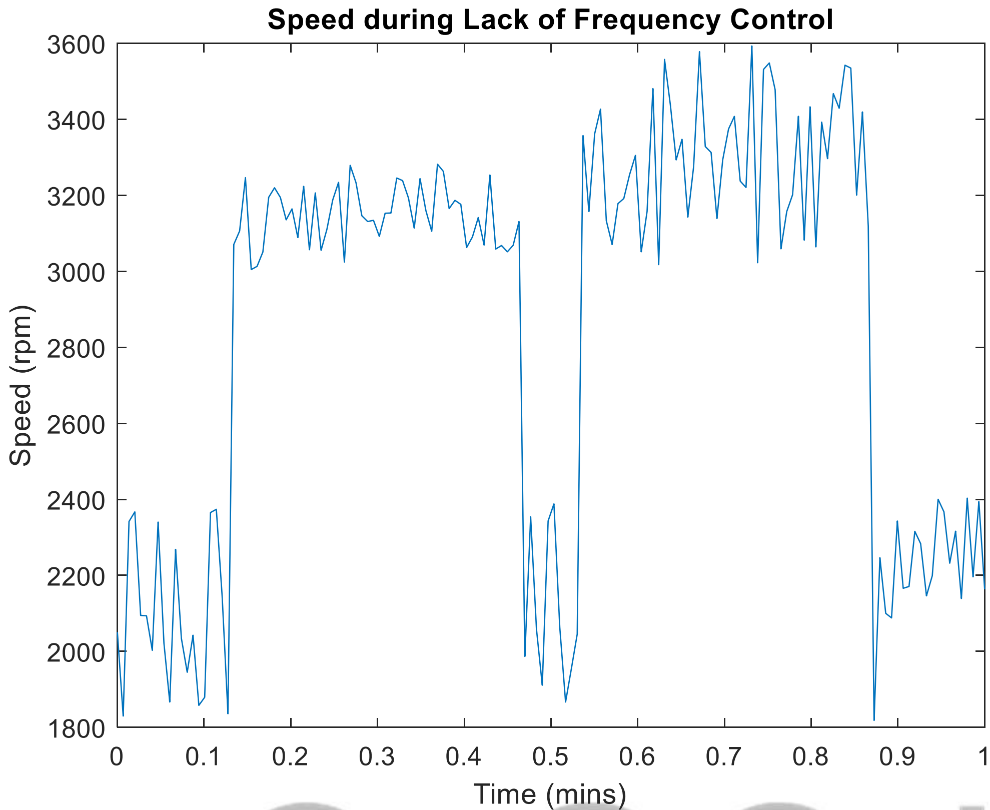
The plot for the temperature of the system at lack of frequency control condition was shown below



Temperature of the synchronous generator lack of frequency control

The temperature during the occurrence of lack of frequency control was shown above. It was observed that there was an unsteady rise of temperature. Hence, once the frequency of the plant is out of control, the temperature increases continuously.

The plot for the speed of the system at lack of frequency control condition was shown below



Speed of the synchronous generator at lack of frequency control

The speed of the generator during the occurrence of lack of frequency control technical fault was shown above. It was observed that the speed was highly unsteady as it shows a partial sinusoidal effect of constantly rising and falling. This implies that once the frequency of the generator is out of control, the speed remains out of control.

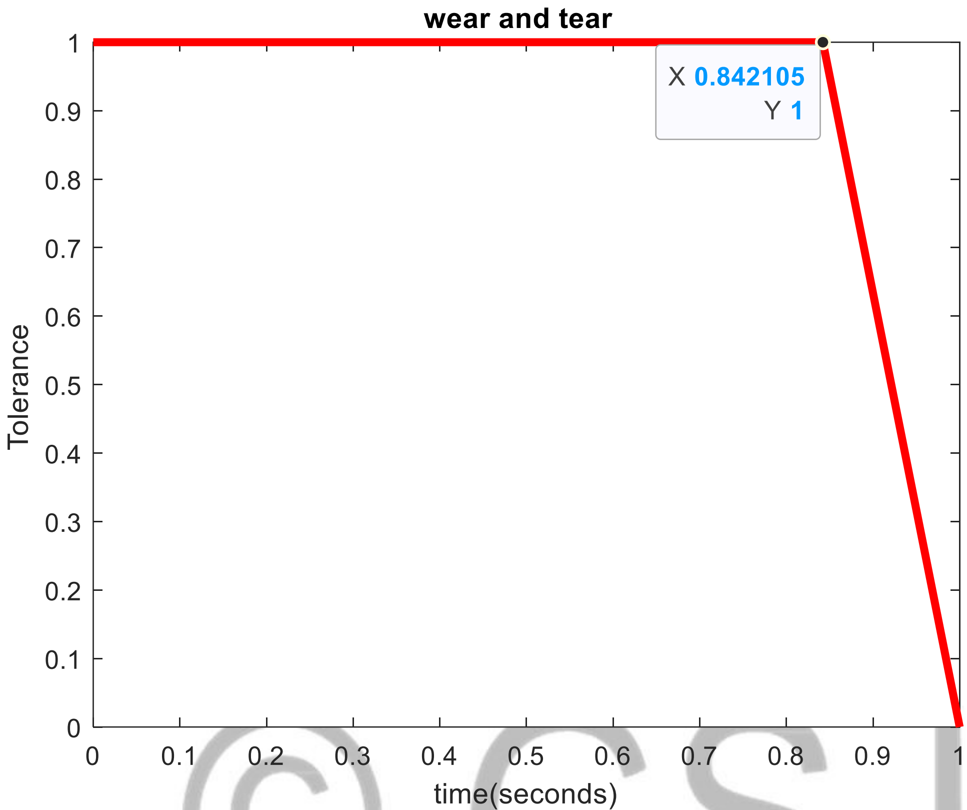
Results of the Fault detection and Mitigation Process with ANN

The fault detection and classification with ANN was shown below

Technical fault detection and classification

Plant issues/ condition	Code	ANN
Normal condition	1	1.03
Occurrence of wear and tear	2	2.99927
Lack of frequency control	3	3.0067

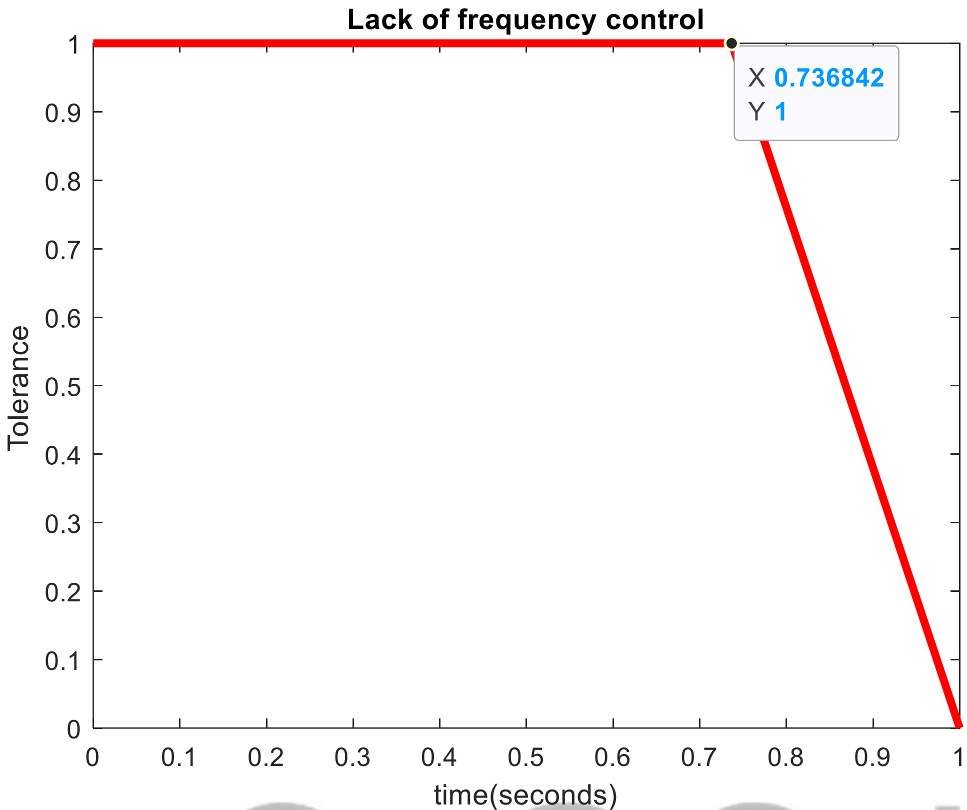
Occurrence of wear and tear fault mitigation time span with ANN was shown below



Occurrence of wear and tear fault mitigation process

The mitigation of wear and tear fault in the synchronous generator with ANN was presented in above. It was found that the level of fault mitigation was 84.21%. This implied that the generator operated at 84.21% from the fault commencement prior to repairs and maintenance of the generator.

The Lack of frequency control fault mitigation time span with ANN was shown below



Lack of frequency control fault mitigation process

The mitigation of lack of frequency control in the synchronous generator with ANN was presented above. It was found that the level of fault mitigation was 73.68%. This implied that the generator operated at 73.68% from the fault commencement prior to repairs and maintenance of the generator.

Conclusion

Faults in synchronous generators result to the shutdown of the plant leading to power failure. This was as a result of the inability to carry out prompt detection and mitigation of the faults which allows response to the maintenance of the generator to prevent shutdown. The plant performance was determined and the faults occurrence was detected and mitigated using ANN. The configured ANN model was sent to the generator model to determine the analytical performance of the ANN model. The outcome from the simulation showed a high level of lack of frequency control and occurrence of wear and tear in the generator. Some of the impacts on speed and temperature are unsteady projection with some resulting in the shutdown of the generation plant.

REFERENCES

Adamsab, K. (2021). Machine learning algorithms for rotating machinery bearing fault diagnostics. Materials Today: Proceedings, 44, 4931-4933.

Al-Greer, M., Bashir, I., Demirel, A., & Keysan, O. (2023). Autonomous fault detection and diagnosis for permanent magnet synchronous motors using combined variational mode decomposition, the Hilbert-Huang transform, and a convolutional neural network. Computers and Electrical Engineering, 110, 108894.

AlShorman, O., Irfan, M., Saad, N., Zhen, D., Haider, N., Glowacz, A., & AlShorman, A.(2020). A review of artificial intelligence methods for condition monitoring and fault diagnosis of rolling element bearings for induction motor. Shock and vibration, 2020(1), 8843759.

Akbar, S., Vaimann, T., Asad, B., Kallaste, A., Sardar, M. U., & Kudelina, K. (2023). State-of-the-art techniques for fault diagnosis in electrical machines: advancements and future directions. Energies, 16(17), 6345.

Asanya.O.N, Uju.I.U., S.E.Abonyi, Ozor.G.O. (2023); Enhancing Rotor Angle Stability of Synchronous Generators Using Neuro-Fuzzy Excitation Control Model, International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS), 7(4), DOI: https://doi.org/10.51583/IJLTEMAS.2023.12405.

Baghdasaryan, M., Ulikyan, A., & Arakelyan, A. (2023). Application of an artificial neural network for detecting, classifying, and making decisions about asymmetric short circuits in asynchronous generator. Energies, 16(6), 2703.

Benkaihoul, S., Mazouz, L., Naas, T. T., Yıldırım, Ö.,& Regaz, A. (2024). Magnetic rotor breakage study in permanent magnet synchronous motor at COMSOL multiphysics and fault detection using machine learning. Studies in Engineering and Exact Sciences, 5(1), 603-618.

Felix (2023), Engineering Based Process of Achieving a Constant Power Supply in Nigeria Global Scientific Journal, 11(9)2320-9186

Isidore U, Asiwe, Uchechukwu M And Uju. (2018). Skewing Impact on Stray Losses of an Induction Motor. International Journal of Trend in Scientific Research and Development. 4(2), 287-294

Otor, Emmanuel, Uju I, U., Nwosu A. W., Imo F. U. (2024). Enhancing Permanent Magnetic Synchronous Motors Performance Characters using the Combination of Vector Control and Model Predictive Control. International Journal of Progressive Research in Engineering Management and Science 4(9) 1264-1276.

Uchechukwu M., Asiwe, Isidore U., Uju, Iloh John Paul (2022). Energy Consumption Minimization of Squirrel Cage Induction Motor Using Classical Optimal Controller Techniques. International Journal of Trend in Scientific Research and Development. 2022 6